PULSE SLOPE MODULATION—A NEW METHOD OF MODULATING VIDEO PULSES AND ITS POSSIBLE APPLICATION ON LINE CIRCUITS

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Plate XVII

ABSTRACT. Pulse slope modulation, a new method of modulating video pulses has been realised by using a rectangular gating pulse feeding an integrating circuit The charging current to the integrating capacity has been made to vary according as the signal voltage. Demodulation is performed by differentiating the slope-modulated pulses and by passing the resultant modulated pulses through memory circuit and low-pass filter.

Possible applications of these pulses on line circuits have been studied, and successful transmission of these through a 100 mile long open wire circuit has been shown.

Signal/noise ratio and linearity of modulation have been found to be very satisfactory and possibility of a more advantageous time-division multiplex system is indicated.

1. INTRODUCTION

The development of the different types of pulse modulation (Flood, 1953) like P.A.M., P.D.M., P.P.M., and P. F. M. has been based on the variation of particular characteristics of the generated pulses. The rise-time of the pulses is one of the important characteristics and an attempt has been made to utilise this rise-time characteristic in developing a new method of pulse modulation.

It is known that on integration of a step function, the slope of the ideally integrated function is dependent on the amplitude of the step function and the constants of the integrating circuit. Further, on differentiation of a linear ramp function, the magnitude of the step function, thus generated, is dependent on the slope of the original function. The above facts have been utilised in modulating and demodulating the sampling pulses. A rectangular pulse is used as a gating pulse to a constant current charging circuit. Ideally the output pulse will have its front edge inclined—the slope depending on the value of R and C of the charging circuit. The modulating signal is made to vary the value of R and hence the slope of the output pulse.

Demodulation is carried out by differentiating the variable-sloped pulses and the resulting variable amplitude pulses are passed through a memory circuit and a low-pass filter to give the original signal voltage.

Possible application of the slope-modulated video pulses to the line circuit has been studied and it is found that with simple R-C semi-differentiating network, good equalisation of loss-frequency distortion produced in the line, is possible. Due to the restricted frequency band-width in lines, trapezoidal pulses are used instead of rectangular pulses.

By using slicing process and narrow gate pulses for the differentiated amplitude modulated pulses, very high degree of 'noise and interference' reduction is attainable by the method.

2. THEORY OF MODULATION AND DEMODULATION

A. *Modulation*: It has been shown that (figure 1) when switch opens at time $t=0$, the current i is given by (Chance et al, 1949)

$$i=I_0 \epsilon^{-t/RC} \quad (t \geq 0)$$

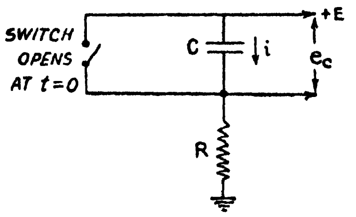


FIG 1. CHARGING CIRCUIT

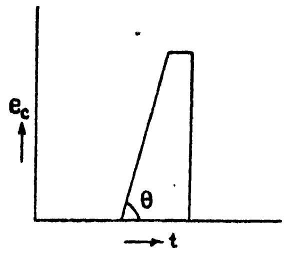


FIG 2 SLOPE-MODULATED PULSE

and the voltage across the condenser is given by,

$$e_c=E\,(1-\epsilon^{-t/RC}),$$

and the slope $$\frac{de_c}{dt}=\frac{I_0}{c}\,\epsilon^{-t/RC} \qquad \ldots \quad (1)$$

and expressed in power series form

$$e_c=E\left[t/RC-\frac{(t/RC)^2}{2!}+\frac{(t/RC)^3}{3!}-\ldots\ldots\ldots\right]$$

If the time for which the switch remains open is small compared to RC, then the charging current will be nearly constant during the charging period, and the voltage

$$e_c=(E/RC)t$$

By using a constant current pentode in place of R, the condenser is charged at constant current and hence the equation

$$e_c=\frac{1}{C}\int_0^t i\,dt$$

is modified in the form $e_c=I_0 t/C$ when $I_0=$ constant current through pentode. This is the equation applicable to the modulating circuit used in this system.

If the modulating voltage $A \sin \varphi$ is made to vary the pentode current I_0 in such a way that

$I_0 = I_m\,(1 + KA \sin\varphi)$ when I_m = pentode current with no modulation,

then,
$$e_c = \frac{I_m}{C}\,(1 + KA \sin\varphi)\,t \qquad \cdots \quad (2)$$

and the slope
$$\frac{de_c}{dt} = \frac{I_m}{C}\,(1 + KA \sin\varphi) \qquad \cdots \quad (3)$$
$$= \tan\theta. \quad \text{[figure 2.]}$$

In equations (2) and (3), although the modulating voltage $A \sin\varphi$ is a time-function of the nature of $\epsilon^{j\omega t}$, the time t for which the switch remains open (*i.e.*, the duration of the sampling pulse) is very small compared to the time period of the modulating signal. Hence $A \sin\varphi$ is taken as constant during time t for the definite integral $\int_0^t i\,dt$ and the differentiation of the resulting sloped edge of the pulse given by equation (3).

B. *Demodulation.*

On differentiation of the voltage e_c, we have the amplitude of the output pulse,

$$\frac{de_c}{dt} = \tan\theta$$
$$= \frac{I_m}{C}\,(1 + KA \sin\varphi)$$
$$= B + K' \sin\phi, \text{ when } B \text{ and } K' \text{ are constants.}$$

Therefore, the output pulse has an amplitude variation proportional to the modulating signal voltage.

In the case of R-C differentiation (figure 3)

$$e_0/e_c = j\omega RC/(1 + j\omega RC) \qquad \cdots \quad (4)$$

whereas, the ideal differentiator should have

$$\frac{e_0}{e_c} = \frac{\frac{d}{dt}(\epsilon^{j\omega t})}{\epsilon^{j\omega t}} = j\omega \qquad \cdots \quad (5)$$

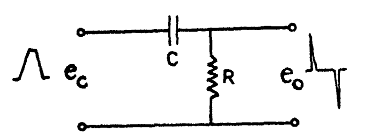


FIG. 3. R-C DIFFERENTIATING CIRCUIT.

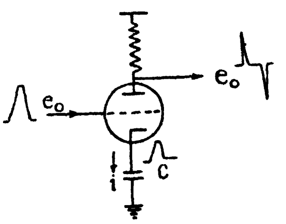


FIG. 4 CATHODE FOLLOWER TYPE DIFFERENTIATOR

when $\epsilon^{j\omega t}$ represents the complex input waveform. Hence it is necessary to use small values of ωRC ($\ll 1$) to make

$$e_0/e_c \simeq j\omega RC.$$

In the case of cathode follower type of differentiator, (figure 4) when the grid voltage rises, the cathode also follows the grid voltage in the same phase and hence

$$e_c = \frac{M}{C}\int^t idt, \text{ where } M \text{ is a constant.}$$

$$de_c/dt = Mi/C \qquad \dots \quad (6)$$

This charging current produces a voltage drop at the anode given by,

$$e_0 = Ri = \frac{RC}{M}\frac{de_c}{dt}$$

Hence, the output is proportional to the slope of the input pulses.

3. CIRCUIT TECHNIQUE

A. *Modulation*: As the sampling frequency has to be at least twice the highest modulating frequency, the pulse repetition frequency is chosen to be 10 kc/s. By the use of square wave generator, differentiating amplifier and limiting wave-shaper, a variable width pulse train is generated. The width of the pulses is variable from 2 microseconds to 20 microseconds. In the particular experiment with the artificial line, 10 microseconds wide pulses are used. Figure 5 shows the block schematic of the pulse generator and modulator. The conventional circuits have not been described (Chance et al, 1949).

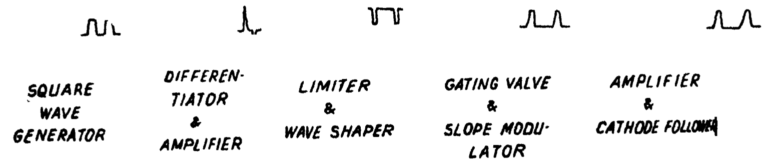


FIG. 5. BLOCK SCHEMATIC OF PULSE GENERATOR & MODULATOR.

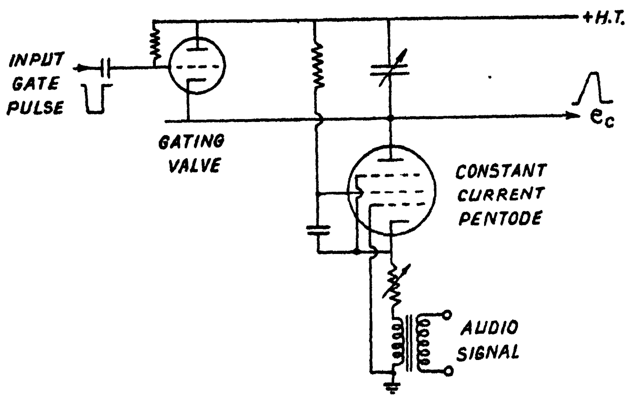


FIG. 6. SLOPE MODULATOR

The slope modulator (figure 6) consists of a gating valve and a charging circuit with a constant current pentode. A negative gating pulse is applied to the switching valve, which, on being cut off, allows the condenser to be charged through the constant current pentode. A cathode degenerative resistance is used to make the charging more linear and to control the value of the effective R of the charging circuit.

The modulating signal is fed through an audio transformer in the cathode circuit and the effective variation of the cathode potential (with respect to the grounded grid) changes the value of the charging current and hence the slope of the leading edge of the output pulse varies accordingly. The production of slope modulation is also possible with the variation of screen potential or grid potential. But the variation of screen potential requires much higher modulating voltage and the variation of grid potential produces slight curvature of the slope of the leading edge of the pulse.

The slope modulated pulse is further amplified and passed through a cathode follower to produce a low impedance output of the order of 1 – 50 volts

FIG. 7(a) UNMODULATED PULSES

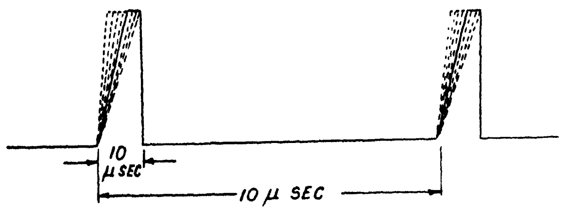


FIG. 7 (b) MODULATED PULSES

peak. Figure 7(*a*) shows the nature of the unmodulated pulses with the leading edges inclined approximately half-way between extreme possible positions. Figure 7(*b*) shows the nature of the modulated pulses and the dotted sloping edges show the different positions of the leading edge with different modulating voltages.

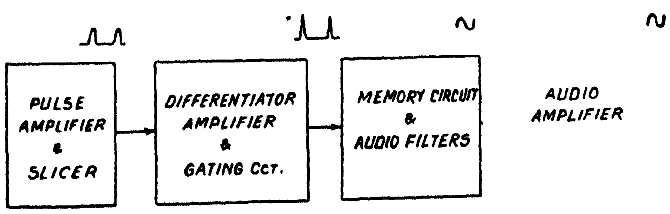


FIG. 8. BLOCK SCHEMATIC OF RECEIVER FOR SLOPE MODULATION.

B. *Demodulation*: Figure 8 shows the block schematic of the receiver used in the system. Amplified slope modulated pulses are passed through the slicer circuit for noise reduction and then differentiated to produce amplitude modulated pulses. A very narrow gate is used after the A.M. pulse amplifier to effect further noise reduction. Finally A.M. pulses are detected in the memory circuit and then passed through the necessary low-pass audio filters and audio amplifiers.

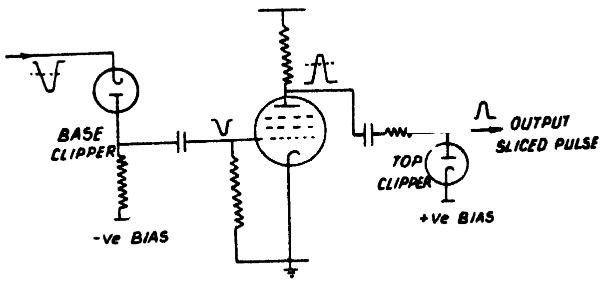


FIG. 9 SLICER CIRCUIT

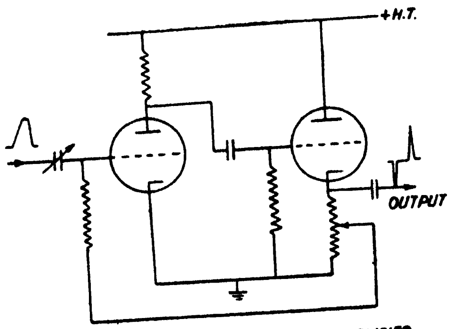


FIG 10 (a). R C DIFFERENTIATING AMPLIFIER.

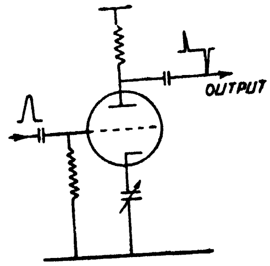


FIG. 10 (b) CATHODE FOLLOWER TYPE DIFFERENTIATOR.

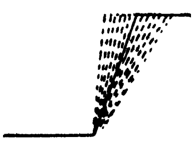


FIG 11 (a) AMPLIFIED MODULATED PULSES.

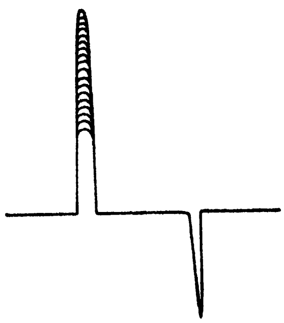


FIG. 11 (b). DIFFERENTIATED AMPLITUDE-MODULATED PULSES. SHOWING AMPLITUDE-VARIATION CORRESPONDING TO THE SLOPE VARIATION OF FIG. 11 (a)

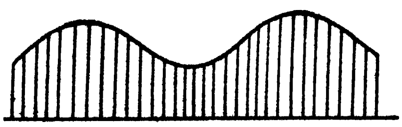


FIG. 11 (c) SHOWING A.M. PULSES ON SLOW TIME BASE.

FIG. 11 (d) DEMODULATED AND DETECTED AUDIO SIGNAL BEFORE THE FINAL FILTER CIRCUIT.

Many slicer circuits are in vogue. A simple circuit is shown in figure 9. Negative and positive bias on the clipper diodes are adjusted depending upon the noise level in the circuit. The simple differentiator may be either a R-C differentiating amplifier or a cathode follower type differentiator as shown in figure 10. In both the cases the product $R\ C$ is very small, as explained in the theory (Section 2).

The gate-pulse can be applied to the next amplifier to select only the A.M. pulses and stop the spurious noise in between the pulses. Nature of the differentiated pulses and the audio output from the memory circuit are shown in figure 11. The process of the complete detection of the information signal is evident and the reproduction is seen to be fairly faithful.

4. APPLICATION ON LINE CIRCUITS

A. *Fourier analysis and frequency bandwidth* : The generated pulses with considerable rise-time may be considered as trapezoidal pulses and their amplitude spectrum can be calculated by Fourier analysis. Figure 12 shows a

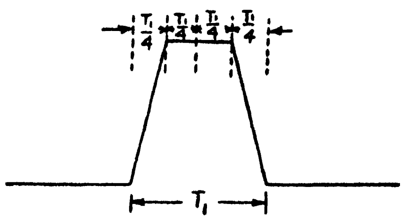


FIG. 12 TRAPEZOIDAL PULSES.

symmetrical trapezoidal pulse with repetition frequency $=1/T_0$, pulse duration $=T_1$, rise-time $= T_1/4$, and peak voltage $= E$.

The amplitude of the nth harmonic is given by Cherry (1949)

$$a_n = \frac{4ET_0}{\pi^2 n^2 T_1}\left(\cos\frac{\pi n T_1}{T_0} - \cos\frac{\pi n T_1}{2T_0} \right)$$

$$= \frac{40E}{\pi^2}\left[\frac{\cos \pi n/10 - \cos \pi n/20}{n^2} \right]$$

where $T_0/T_1 = 10$, repetition frequency $= 10$ kc/s, pulse duration $=10\ \mu$ sec.

The energy of the nth harmonic is given by

$$E_n = a_n^2 = \left[\frac{40E}{\pi^2 n^2}(\cos \pi n/10 - \cos \pi n/20) \right]^2$$

Table I gives the values of $[(\cos \pi n/10) - (\cos \pi n/20)]/n^2$ proportional to a_n and the values of $[\{(\cos \pi n/10) - (\cos \pi n/20)\}/n^2]^2$ proportional to the energy of the nth harmonic.

TABLE I

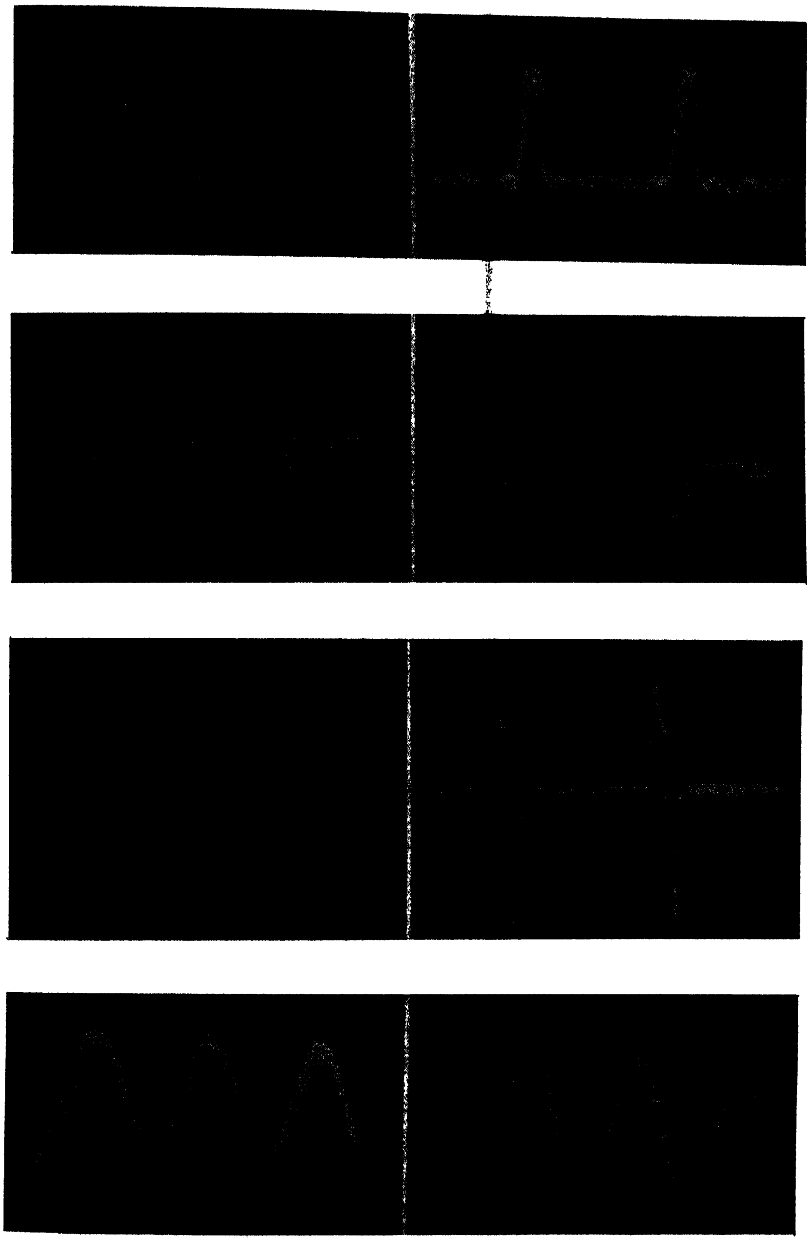
No. of the harmonics	Amplitude of the nth harmonic $\propto \left(\dfrac{\cos \pi n/10 - \cos \pi n/20}{n^2}\right)$	Energy of the nth harmonic $\propto \left(\dfrac{\cos \pi n/10 - \cos \pi n/20}{n^2}\right)^2$
1st	−.0366	.001340
2nd	−.0355	.00126
3rd	−.0337	.001136
4th	−.03125	.0009765
5th	−.0283	.0008009
6th	−.0249	.00062
7th	−.021125	.0004515
8th	−.0175	.0003065
9th	−.0133	.0001769
10th	−.01	.0001
11th	−.00657	.00004316
12th	−.00347	.00001204
13th	−.00079	.0000006241
14th	−.0014	.00000196
15th	+.0034	.00001156
16th	+.0044	.00001936
17th	+.0051	.00002601
18th	+.0054	.00002916
19th	+.0054	.00002916
20th	+.0052	.00000675

Figure 13 shows the graphical relation between the nth harmonics and their energy content.

It is seen that the energy of the 12th harmonic (equal to 120 kc/s) is less than 1% of that of the fundamental and the energy of the 18th and 19th harmonics (corresponding to 180 kc/s and 190 kc/s) is about 2% of that of the fundamental. It is clear that the band width required for these pulses is only 120 kc/s for average transmission and 200 kc/s for faithful transmission.

The characteristics of an open-wire line are such that their loss-frequency relation is parabolic in nature between 10 kc/s and 300 kc/s., the loss being given by,

$$\alpha = A + \left(\frac{k}{276} \cdot \frac{\sqrt{f}}{b} \cdot \frac{b/a}{\log b/a} \right)$$



(*i*) Unmodulated transmitted pulses. (*ii*) Modulated transmitted pulses. The thickness of the starting edges is due to modulation. (*iii*) Unmodulated received amplified pulses after passage through the artificial line. (*iv*) Received modulated pulses. Thickness of the starting edge is due to modulation. (*v*) Differentiated pulses on a slow time-base showing the amplitude modulation. (*vi*) Differentiated pulses. Thickness of the positive pulses is due to the variation of the pulse amplitudes due to modulation. (*vii*) Demodulated audio signal before the final filter circuit. (*viii*) Modulating audio signal (1 kc/s).

and is proportional to $\sqrt{f}$, where k=constant, f=frequency, b/a=ratio of diameter and spacing of wires, and A=constant.

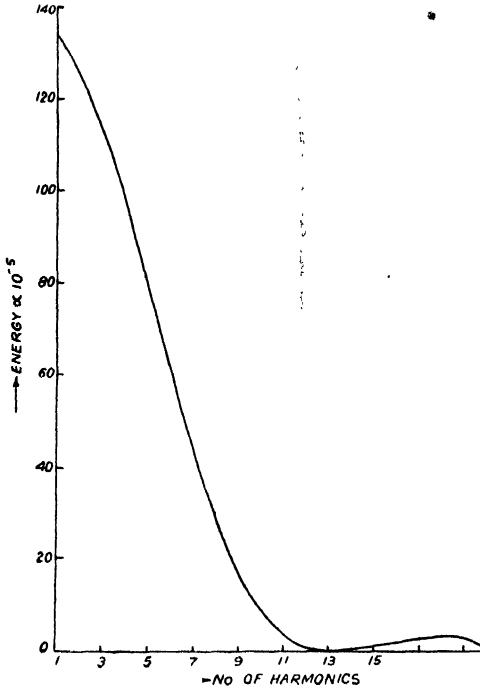


FIG. 13. Energy spectrum of trapezoidal pulses

It is easy to construct a compensating network for losses of this nature and the line equipments working at frequencies upto 140 kc/s are in use. It is, therefore, reasonable to expect that transmission of 10 microseconds video pulses in open-wire line circuit will be possible and the distortion in the frequency band 10 kc/s to 120 kc/s, as required by the system, can easily be compensated by suitable networks.

B. *Tests with Artificial Line*

Pulse communication systems are now well established in the U. H. F. and microwave bands. But very little work (Moss and Park, 1947) has been done to find out the possibilities of pulse applications on line circuits. As seen from the Fourier analysis, a comparatively wide pulse of trapezoidal shape requires much lesser band-width than the rectangular pulses usually used in the microwave pulse communication system. It is expected that even with greater bandwidth requirements than the current carrier equipments, more efficient system of 'line communication equipment' can be devised on the principles stated in this paper.

In order to study experimentally the response of the video pulses in lines, a number of constant resistance L-type net-works with inverse arms were constructed and connected in tendem to simulate the loss characteristics of a

100-mile long open-wire line (of 12 in. spacing 300 lb. copper-wire). The actual characteristic as measured, is shown in figure 14. The curve represents

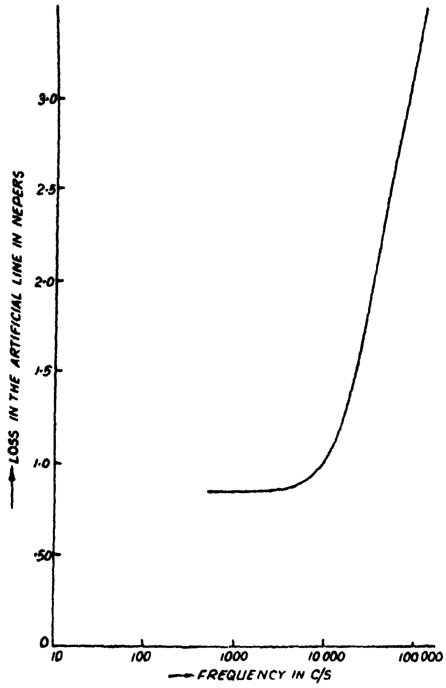


FIG. 14. Characteristics of the artificial line $Z_0 = 600\ \Omega$

the loss characteristic of an actual line very fairly. The impedance of the artificial line varied between 500 and 600 ohms within the measured frequency band.

The nature of the received pulses are shown in figure 15(*a*). It is apparent that the line has a sort of integrating effect on the shape of the

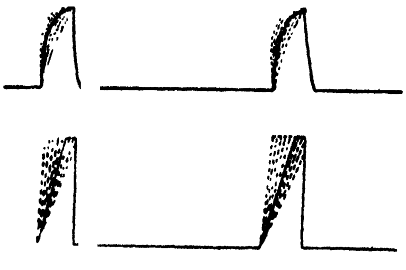


FIG. 15 (a). NATURE OF THE RECEIVED PULSES (UNEQUALISED)

FIG 15 (b). EQUALISED RECEIVED PULSES.

pulses and they are slightly widened. But the pulses are not beyond recognition and the slope characteristic persists without any evident distortion.

The problem of equalisation has been successfully dealt with much simpler networks than are used in the current line communication equipments. It is only necessary to use a simple R-C semi-differentiating network to re-shape the partially integrated pulses (figure 15(*b*).

The circuit arrangement for equalisation is shown in figure 16. The value of *RC* is dependent on the amount of distortion produced in the line. To compensate for the seasonal and climatic variation of line characteristics,

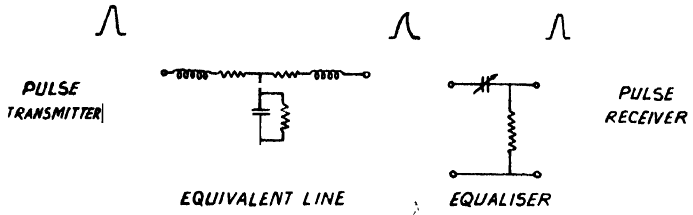


FIG 16. EQUALISER CIRCUIT

a bias-controlled pentode can be used as the resistance component of the R-C equalising network. The grid-bias of the pentode may be varied automatically in synchronism with the variable line loss and hence the effective resistance will vary synchronously.

A time division multiplex system suitable for the line circuits can be evolved on the basis of this promising result and our existing knowledge of similar systems. The work is in progress to produce a specific equipment which can replace some of the present carrier current equipment with better advantage. The long distance signalling can be accomplished either by suppressing the pulses during ringing or usual tone signalling can be utilized.

The loss in average signal level, as measured by a wide-band average detector type levelmeter, is 19.5 bd. This is the approximate loss of 100 kc/s signals on a similar 100-mile open-wire circuit.

4. PERFORMANCE

A. *Interference and Noise*: Types of interference and noise in a pulse communication system may be classified as below:

(*a*) Amplitude modulation of the base line and the top line of the pulse train by the interfering signal (A. M. or F. M. or P. M.).

(*b*) Partial cancellation of the pulses due to overlapping interfering pulses received in phase opposition.

(*c*) Spurious time-shifts of the pulse edges due to the overlapping pulse envelope of an interfering station.

(*d*) Random fluctuation noise, generally in the nature of random pulses on the base and top line of the signal pulses.

Analysis of the effects of the above in the slope modulated system is similar to the analysis of P. D. M. and P. P. M. as done by Kretzmer, (1950), except in the case of time-shift effect.

The main key to the noise reducing property of pulse modulation is the slicing process. Both theory and experiments show that the optimum value of the slicing level is half the peak signal voltage, taking all types of interference and noise into consideration. Further, for maximum signal/noise ratio in the output, the thickness of the slice of the pulse should not exceed a few per cent of the pulse height and the width of the gating pulse should be as small as possible. The resultant ideal signal level is 6 db above the noise level for perfect noise-free reception.

In case of slope modulation, this ideal cannot be reached even theoretically. To obtain the information back, an appreciable percentage of the pulse height is to be sliced as the leading edge of the pulse slice has to be differentiated. It is found that the thickness of the slice should be about

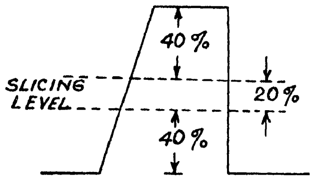


FIG. 17. SLICING LEVEL.

20 % of the pulse height for efficient differentiation (figure 17). Hence the slicing level is at 40 % of the pulse height and the allowable signal/noise ratio = 8 db for noise-free reception.

With respect to the time-shift effect it is seen that the resultant noise should be very small as the output information is dependent not on the

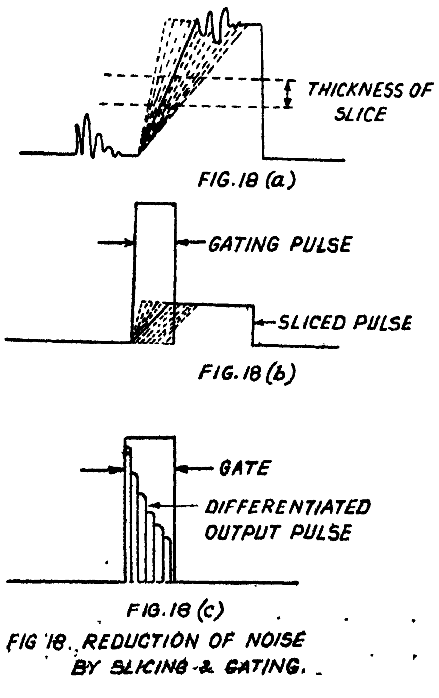


FIG 18. REDUCTION OF NOISE BY SLICING & GATING.

position of the leading edge of the pulses as in P. D. M., but on the slope.

All the other three types of interference have to be dealt with by efficient slicing and faithful differentiation of the slope.

Production of spurious signal (pulses) at the output of the slicer; when the noise level is above the slicing level, can be nullified by using a narrow gating pulse in the amplifier after the differentiator, so that only the information carrying differentiated narrow pulses corresponding to the leading edge of the transmitted pulses are selected and further amplified and demodulated (figure 18). This process will effectively bring the performance of the system similar to those using narrow pulses, although here considerably wider pulses are transmitted.

B. Modulation Characteristics.

Linearity of modulation with different input levels has been studied and it is found that the input/output characteristic is linear over a range of 35 db as shown in figure 19. The level of audio input at the modulator and the level of audio output at the demodulated audio amplifier have been

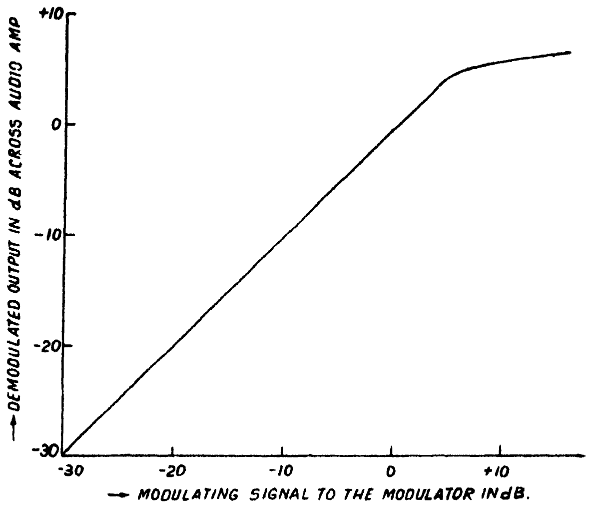


FIG 19 INPUT/OUTPUT CHARACTERISTIC OF MODULATION

measured. The curve shows saturation after +5 db input and this is the point where further slope variation of the trapezoidal pulse decreases the amplitude of the triangular pulse formed on maximum positive modulation. However, the linearity seen in the graph is enough to accommodate the level variation in average audio channels of a telephone circuit (approximately 30 db).

5. DISCUSSION

Although the performance of this slope modulation is similar to that of P. D. M. and P. P. M. (Kretzmer, 1950 and Earp, 1948) and much better than P. A. M., the space occupied by each channel pulses on a time division multiplex scheme remains the same with and without modulation. Using pulses of equal duration, slope modulated system will provide more channels than P. D. M. and P. P. M. Conversely, for the same number of required channels wider pulses can be used in slope modulation and hence lesser band-width is required for faithful transmission. It may become difficult in producing slope modulation in extremely narrow pulses, but slope modulation of pulses of the order of two microseconds and above, as used in microwave pulse communication equipment, is easily done with simple circuit technique.

Considering the overall circuit technique involved in transmission and reception of slope modulated signals, it is seen to be simpler than P. P. M. and is equally simple as P. D. M. and P. A. M. In its application in line circuits, equalisation is very simple and the conversion of four-wire circuit to two-wire working may be easily done by adequate gate pulses incorporated in the receiver.

The system has further advantage that due to its complexity in demodulation, it will maintain more secrecy than P. D. M. and P. A. M. and offers a suitable application as mobile sets behind the front line for defence purposes.

It is further estimated that a slope modulated time-division multiplex system providing two or four channels will compare very favourably with the existing carrier equipments in respect of performance, simplicity, maintenance and cost.

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